COMPOSITE MATERIAL FOR ACOUSTIC DAMPING

The present invention relates to a composite material for acoustic and mechanical damping and methods for its production. In particular, the present invention relates to such material having advantageous static and dynamic characteristics. That is, the material should be strong enough to be formed into structural components and to bear a static load, while being capable of effectively absorbing acoustic and/or mechanical vibrátions.

The composite materials in question typically have a layer structure. One common example comprises layers of glass fibre matting embedded within an epoxy resin. Such material has a high static strength, but a poor dynamic performance. That is, such material is structurally strong, but has very poor acoustic or mechanical wave damping characteristics.

In many situations, it is required to provide a material which is structurally strong, provides efficient damping of acoustic and/or mechanical vibrations but is lightweight. A material combining all of these features is hitherto unknown to the inventors. For certain applications, it is desirable that such material should also be non-magnetic.

A material known to have good static and dynamic properties is a metal-rubber-metal sandwich structure. Typically, the relative thicknesses of the layers are 4:1:1. The thickness of the rubber layer should be at least half the wavelength of the lowest frequency which is required to be damped. Such material does not provide the characteristics required of the present invention. It is not lightweight, the material is typically steel, for cost considerations and so is typically magnetic, and the structure is liable to delimitation at the interfaces of the metal and rubber layers.

The present invention accordingly provides a stiff, lightweight, preferably non-magnetic material with effective damping properties for acoustic and/or mechanical vibrations. Such material is preferably also available at low cost.

More particularly, the present invention provides a composite material for acoustic or mechanical damping, comprising: a plurality of layers of fibrous material embedded in a solid material, characterised in that the solid material has a composition which varies through a depth of the material, the composition having a relatively high proportion of a first material, being a structural composite resin, and a relatively low proportion of a second material, being a material of high hysteretic loss, at the outer surfaces of the material, and the composition having a damping region between the outer surfaces wherein the composition has a relatively high proportion of the second material and a relatively low proportion of the first material, the composition, the composition of the solid material varying through a gradual change in composition between the damping region and the outer surfaces, such that the material contains no abrupt changes in composition.

The first material may be an epoxy or polyester resin. The second material may be polyurethane. The fibrous material may be glass fibre matting.

The present invention also provides a method for producing a composite material for acoustic damping, comprising the steps of:

- providing at least one first fibrous layer impregnated with a first thermosetting material;
- stacking the at least one first fibrous layer on a former;
- providing at least one second fibrous layer impregnated with a second thermosetting material;
- stacking the at least one second fibrous layer on the stack of the first fibrous layer(s);
- providing at least one third fibrous layer impregnated with a third thermosetting material;
- stacking the at least one third fibrous layer on the stack of first and second fibrous layers; and
- simultaneously heating and compressing the resulting stack of first, second and third fibrous layers to harden the thermosetting materials,

wherein the second thermosetting material comprises an effective proportion of a high hysteretic loss material, and the first and third materials comprise an effective proportion of a structural composite resin, further characterised in that the heating and compressing step is effective to cause the second material to diffuse or intermingle with both the first and second materials.

The first and/or third material may comprises an epoxy or polyester resin. The second material may comprise polyurethane. The fibrous layers may comprise glass fibre matting.

The method may further comprise the step of selecting the direction of the fibres of the fibrous layers to provide a desired combination of structural strength and damping properties.

The above, and further, objects, characteristics and features of the present invention will become more apparent from consideration of the following description of certain embodiments thereof, in conjunction with the accompanying drawings, wherein

Figs. 1A-7A show partially cross-sectional views of materials according to embodiments of the present invention;

Figs. 1B-7B show curves illustrating relative composition of solid material at varying depths within the respective material;

Figs. 8-11 show woven fibrous layers suitable for inclusion in the material of the present invention;

Fig. 12 shows, in cut-away plan view, several woven fibrous layers of an embodiment of the present invention; and

Fig. 13 shows comparative test results of a sample of the material of the presnet invention compared to a sample of conventional material.

Fig. 1A shows a material 10 according to an embodiment of the invention. The material comprises a number of fibrous layers 12. The illustration of Figs 1A-7A is expanded in thickness for ease of understanding. In reality, the fibrous layers 12 will be more closely packed than shown in the drawings. Each of the fibrous layers may comprise a woven or non-woven fibrous material, such as a glass fibre cloth, or carbon fibre matting, KEVLAR (TM) or steel mesh, or any other structurally strong fibrous material. The fibrous layers are embedded within a solid material 14. The composition of the solid material forms an aspect of the present invention, and this aspect will be described first.

According to an aspect of the present invention, the solid material 14 comprises a structural composite resin and a material of high hysteretic loss. Examples of the structural composite resin include epoxy and polyurethane resins. Examples of the material of high hysteretic loss material include polyurethane, polyesters, vinyl esters. and other polymer matrices.

The inventors have found that epoxy resin is an inexpensive but effective material for the structural composite resin. The inventors have also found that polyurethane is an inexpensive yet effective material for the material of high hysteretic loss. The inventors have also found that glass fibre cloth is an inexpensive but effective material for the fibrous layers. These materials will be referred to throughout the present description. However, such references are not to be construed as limiting and other materials, such as those listed above, may be used provided that they have the required properties.

Fig. 1B shows the variation of the composition profile of the solid material 14 with depth z into the material. The percentage composition of high hysteretic loss material is shown by line 16, while the percentage composition of epoxy resin is shown by line 18. The embodiment shown in Fig. 1A mimics the 4:1:1 relative thickness ratio known from the prior art metal:rubber:metal structures. The upper surface 20 (z=0) of the material has a high, in this case 100%, proportion of the epoxy resin. Similarly, the

lower surface 22 of the material has a high, in this case 100%, proportion of the epoxy resin. An intermediate region 24 has a relatively low, in this case down to 0%, proportion of the structural composite resin, and a relatively high, in this case up to 100%, proportion of the high hysteretic loss material.

The region 24is not a discrete layer with interfaces as such. For this reason, the region is shown in phantom on Fig. 1A, the boundaries shown indicating the transition between a greater than 50% proportion of high hysteretic loss material within the region 24 to a lower than 50% proportion outside of such region.

This is an important feature of the present invention. By avoiding the formation of an interface as such, and replacing it with a gradual transition in the composition of the material, the material of the present invention avoids the problem of laminate shear, whereby known laminates including a damping layer were liable to delaminate due to the high shear stresses occurring at the interface between the structural layers and the damping layer.

In use, the lower region 26 provides structural strength. The material of the invention may be used for soundproof cladding, in which the material need only be self-supporting, or may be structural in the sense of bearing a significant static applied load. The majority of the applied static load will be borne by the region 26, and the materials of the solid 14 and the fibrous layers 12 should be chosen and dimensioned according to the required mechanical strength. The intermediate layer 24 functions as an absorber of acoustic or mechanical vibrations. Upper layer 28 provides a hard outer surface, allows the intermediate layer 24 to function, as will be described below, and may acts as a receiver of the vibrations to be damped. Upper and/or lower surfaces 20, 22 may be provided with a decorative layer integral to the material 10.

When an acoustic or mechanical vibration is applied to the stiff upper layer 28, such layer transmits the vibrations though to the layer 24. The upper layer 28 will flex to some extent under the influence of the vibrations. Such flexing will cause tension

within the fibres of the fibrous layers 12. These fibrous layers will disperse the stresses in layer 28 caused by the acoustic or mechanical vibration over a larger area of the upper layer 28 than would be the case in the absence of the fibrous material. The stiff layer 28 conveys the vibration of this larger area of upper layer 28 to a correspondingly sized portion of the layer 24. Thus, the fibrous layers 12 function to spread the applied vibrations over a larger area of layers 28 and 24. This is in addition to their well-known properties of adding structural strength. The layer 24 comprises a relatively high proportion of the material of high hysteretic loss. This material will absorb a large proportion of the applied vibration, converting it into a small amount of heat. Very little of the originally applied vibration will reach the structural layer 26, and the material has accordingly performed its intended function of damping the applied vibrations. Similarly, acoustic or mechanical vibrations applied to the structural layer 26 will be damped by layer 24, and very little of the applied vibration will reach the upper layer 28.

The thickness of layer 24 should be at least equal to one-half of the wavelength of the lowest frequency vibration which it is intended to damp. Typically, the material of the present invention may be made to effectively damp acoustic waves of 200Hz and above, while having a thickness in the range of 4-6mm.

As has already been mentioned, layer 24 is not a discrete layer with interfaces as such. Rather, the composition of the material 14 varies gradually from a 100% epoxy resin composition at the upper surface through a range of intermediate compositions to reach 100% high hysteretic loss material within layer 24 and through a second range of intermediate compositions until it returns to 100% epoxy resin for the lower surface 22.

The particular composition and dimensions described with reference to Fig. 1 are only one example of the type of materials provided by the present invention. Further examples are described below.

An example of a method for producing the material of Fig. 1A will now be described. A former is first provided. This may be in the form of a flat surface, or may be in the form of an article to be produced in the material of the invention. A first layer of fibrous material 12 is impregnated with the structural composite resin, such as an epoxy resin, and the layer is applied to the former. Further such layers may be stacked onto the first such layer. At least one layer of fibrous material 12 is then impregnated with the high hysteretic loss material, such as polyurethane, and is laid onto the stack of layers. Further such layers may be applied. Finally, at least one further layer of fibrous material is impregnated with a structural composite resin, such as an epoxy resin, and is laid over the stack of layers described. The resulting assembly will be a "sandwich" structure, having layers of fibrous material impregnated with the high hysteretic loss material, such as polyurethane, between layers of fibrous material impregnated with the structural composite resin, such as an epoxy resin. the materials used for the structural composite resin of layers 26 and 28 may be different from each other, or may be the same.

The resulting assembly is then compressed and heated, according to techniques known in themselves, to cure the solid materials 14, such as epoxy resin and polyurethane.

According to a feature of the present invention, the materials chosen for the structural composite resin and the material of high hysteretic loss should both have a relatively low viscosity state at a same temperature within the curing process. As the structure is heated, the structural composite resin(s) and high hysteretic loss materials pass through the temperature at which they are all of relatively low viscosity. During this time, the materials diffuse or intermingle, providing the gradual material transition with depth as shown in Fig. 1B. The rate of transition of the material composition may be reduced by increasing the time that the structure is held at a temperature at which all the structural composite resin(s) and high hysteretic loss materials are all of relatively low viscosity.

The structure is then further heated to cure the structural composite resin(s) and high hysteretic loss materials. The resulting structure is then allowed to cool and is removed

from the former. Decorative layers may be applied as the first and/or last layers in the stack of fibrous layers. The compressing step may be performed by applying an upper former to the assembly of fibrous layers and applying pressure. The former(s) may each have a decorative pattern applied which may be transferred to the structure of the material of the present invention. The compressing step may alternatively be performed by enclosing the stack of fibrous material layers within a further layer of a material which is relatively inert, but which shrinks at the temperatures required for curing. The inventors have found that a polyamide cloth tape is suitable.

Figs. 2A and 2B show material 101 according to a second embodiment of the present invention. The views shown in Figs. 2A and 2B correspond to those shown in Figs. 1A and 1B respectively.

As shown in Fig. 2B, the material 101 of this embodiment differs from the material 10 of the embodiment shown in Figs. 1A and 1B in that the composition of the layer 24 does not attain 100% of the material of high hysteretic loss. As shown, once again, the layer 24 is indicated as the zone having greater than 50% composition 16 of the high hysteretic loss material within the solid material 14. The material of Fig. 2A, 2B may be formed by a similar process to that described for the material of Figs. 1A and 1B, but holding the stack of fibrous layers at the temperature at which , the structural composite resin(s) and high hysteretic loss materials are all of relatively low viscosity. An increased amount of interdiffusion of intermixing or intermingling will cause a lower peak composition of the material of high hysteretic loss, but that material will be dispersed through an increased range of depths of the material. Such material may be expected to have a greater structural strength than the material of Figs 1A, 1B, but could be expected to be less effective at damping acoustic and mechanical vibrations.

Figs. 3A and 3B show a material 201 according to a further embodiment of the present invention. In this embodiment, the composition does not exceed 50% of the material of high hysteretic loss at any depth. There is a region having a relatively high proportion

of this material, as illustrated by curve 16 in Fig. 3B. However, since this proportion never exceeds 50%, no layers are marked on Fig, 3A.

The material of Fig. 3A, 3B may be formed by a similar process to that described for the material of Figs. 1-2A and 1-2B, but holding the stack of fibrous layers at the temperature at which , the structural composite resin(s) and high hysteretic loss materials are all of relatively low viscosity. An increased amount of interdiffusion of intermixing or intermingling will cause a lower peak composition of the material of high hysteretic loss, but that material will be dispersed through an increased range of depths of the material. Alternatively, the fibrous layers carrying the material of high hysteretic loss may be impregnated with a mixture of structural composite resin with the material of high hysteretic loss . The maximum attainable percentage composition of the material of high hysteretic loss layers will accordingly be limited to the corresponding composition of the mixture in which the corresponding fibrous layers were impregnated.

The material of Figs 3A-3B may be expected to have a greater structural strength than the material of Figs 2A, 2B, but could be expected to be less effective at damping acoustic and mechanical vibrations.

Figs. 4A and 4B show another embodiment of the present invention. The material 301 of Figs. 4A and 4B differs from that of Figs 2A and 2B in that the maximum percentage composition 16 of the polyurethane increases to a maximum, $a\%$, remains at that level for a range of depths z, then reduces again. This material may typically be produced similarly to the material of the preceding embodiments, but the fibrous layers destined to form layer 24 are impregnated with a mixture of $a\%$ polyurethane and $(100-a)\%$ epoxy resin. The properties of this material may be expected to be similar to those of the material of Figs 2A-2B.

Figs. 5A and 5B show material 401 according to a further embodiment of the present invention. The material 401 differs from the material 10 of Fig. 1 in that the layer 24 is

placed substantially centrally within the structure, and that layer has an increased thickness as compared to the material of Figs 1A-1B. This material may by made by changing the relative number and order of the impregnated fibrous layers as applied to the former. This embodiment illustrates that the relative position and thickness of the layers may be varied at will, simply by changing the number and order of the impregnated fibrous layers as they are applied, in order to achieve a desired set of static and dynamic characteristics. The material of Figs 5A and 5B maybe expected to have a lower static (structural) strength than the material of Figs. 1A-1B, but a more effective dynamic characteristic, that is, to be more effective at damping acoustic and mechanical vibrations.

Figs. 6A and 6B show an material 501 according to a further embodiment of the present invention. This material has an even thicker layer 24 than the material of Figs 5A, 5B. A variety of different compositions are shown, and will depend on the material used to initially impregnate the fibrous layers 12 of layer 24. Composition curves 16c, 18c show the composition of a material of Fig. 6A in which the fibrous layers 12 of the layer 24 were impregnated with 100% polyurethane. . Composition curves 16b, 18b show the composition of a material of Fig. 6A in which the fibrous layers 12 of the layer 24 were impregnated with a mixture of approximately 75% polyurethane, 25% epoxy resin. Composition curves 16a, 18a show the composition of a material of Fig. 6A in which the fibrous layers 12 of the layer 24 were impregnated with a mixture of approximately 40% polyurethane, 60% epoxy resin. The materials of Figs 6A, 6B may be expected to have static and dynamic properties commensurate with the thickness and composition of the layers 24, 26, 28 in each case.

Figs. 7A and 7B show a material 601 according to a further embodiment of the present invention. The material of Figs 7A and 7B differs from the materials of previous embodiments principally in that a plurality of layers 24 of relatively high percentage composition of polyurethane (or other material of high hysteretic loss) are provided. Such plurality of layers are separated by separating layers 30 of epoxy resin, or other structural composite resin. Such material may be produced by a method similar to that

described for the material of Figs 1A and 1B, but in which one or more layers of epoxy impregnated fibrous material 12 is placed between groups of at least one polyurethane impregnated fibrous layer.

The material of Figs 7A, 7B may be expected to have a significantly improved dynamic (vibration-damping) characteristic as compared to a similar material having a single layer 24 of thickness equal to the sum of the thicknesses of the layers 24 of Fig. 7A.

As described earlier, one of the functions of the fibrous layers 12 is to disperse the applied vibrations over an increased surface area of the epoxy (structural composite resin) layer receiving the vibrations. This occurs by the vibrations causing flexing of the epoxy layer, which in turn causes tension in the fibres of the layers 12, which causes tension in regions of the fibrous layers distant from the original point of application of the fibres. This causes the applied vibration to be spread over a wider area of the damping layer 12, increasing the overall damping efficiency. This function of spreading the tension can only occur in the direction of the fibres.

Fig. 8 shows a typical fibrous material suitable for use as the fibrous layers in the material according to the invention. A fibrous material, for example, glass fibre cloth, is woven with strands at 0° and 90° to the direction of feed of the material as it is applied. Us of this material will allow stresses applied at a certain point to be disposed at angles of 0° and 90° from the point of impact.

Similarly, Fig. 9 shows another fibrous material suitable for use as the fibrous layers in the material according to the invention. The fibrous material, for example, glass fibre cloth, is woven with strands at 45° and 135° to the direction of feed of the material as it is applied. Us of this material will allow stresses applied at a certain point to be disposed at angles of 45° and 135° from the point of impact.

Similarly, Fig. 10 shows another fibrous material suitable for use as the fibrous layers in the material according to the invention. The fibrous material, for example, glass fibre cloth, is woven with strands at 30° and 120° to the direction of feed of the material as it is applied. Use of this material will allow stresses applied at a certain point to be disposed at angles of 30° and 120° from the point of impact.

According to an aspect of the present invention, use of a certain combination of such materials as the various fibrous layers 12 of the material of the invention allowsapplied stresses to be spread from the point of application in multiple directions, increasing the efficiency of spreading, and correspondingly increasing the effectiveness of the material's vibration damping properties.

According to the desired application, a product produced in the material of the invention may have preferred directions in which stresses could be applied. Stresses could be preferentially directed in those directions by carefully selecting and/or aligning the fibrous material used in the fibrous layers, for example, those shown in Figs. 8-10.

Fig. 11 shows a further fibrous material suitable for use as the fibrous layer of the material of the invention. In this material, which may alternatively be orientated similarly to that shown in Figs 9, 10, or otherwise, one direction of the weave has a significantly greater density of fibres that the other direction. Since tension is transmitted within the layers of the material of the invention along the fibres of the fibrous material, the use of the fibrous material of Fig. 11 will preferentially transmit stresses in the direction of the higher density of fibres. By appropriately selecting and aligning such a fibrous material as one or more of the fibrous layers within the material of the invention, stresses caused by applied acoustic or mechanical vibrations may be preferentially dispersed in selected directions. The requirement for such functionality will be determined by the required characteristics of the article being produced from the material of the present invention.

Fig. 12 illustrates, in cut-away, the fibrous materials of various layers of a sample of material according to the present invention. As can be seen, fibrous material according to each of Figs. 8-11 has been included, as respective fibrous layers within the material. This will provide a particular, and relatively complex, pattern of dispersion of applied stress. It would be unusual to require such a number of different fibrous materials within one sample of the inventive material, and a maximum of two or three different types of material or orientation would be typical.

Fig. 13 shows results of tests performed on a sample of the material of the present invention. Vibrations varying in frequency from 0Hz to 2557Hz were applied to a sample of the material according to the invention, and a sample of conventional GRP, that is, epoxy resin containing glass fibre matting. Curve 50 shows the amplitude of vibration of the sample of conventional GRP over the range of applied frequencies, while curve 60 shows the corresponding amplitude of vibration of the sample of material of the invention over the same range of frequencies. As can be seen, the material of the present invention provides very effective damping of vibration at audio frequencies. At frequencies below about 220Hz, the material of the invention is not effective at damping. This is because the damping layer 24 of the sample had a thickness less than half a wavelength of frequencies of 220Hz and below. This could be cured, of necessary for the intended application of the material, by increasing the thickness of the damping layer.

The invention accordingly provides an inexpensive, rigid, lightweight damping material which is preferably non-magnetic.

Although certain specific materials have been disclosed, these are not limiting and many other materials may be used, depending on cost, the required mechanical characteristics and the required application of the resultant material. The fibrous layer may be composed of conductive material such as carbon fibre or steel mesh, for example to provide RF screening. The fibrous layers may be composed of respectively

different materials, or a fibrous material comprising elements of different materials, such as glass fibre, carbon fibre, copper, steel, may be specially produced and used for particular applications.

The material provided by the present invention finds many industrial applications. For example, automotive dashboards made from the inventive material would reduce noise transmission and would be less likely to rattle. Automotive body parts and other items, such as rudders for boats, may be made from the material of the invention to provide a "luxury" feel, without adding to weight. The mechanical and acoustic damping properties of the material of the invention will mean that such parts do not easily resonate, and behave much as a heavy metal component of much greater mass would behave. Turbine blades could be constructed from the material of the invention. The properties of the material may be varied by using different combinations and compositions of layers, for example to provide very effective damping at the tips of the blades, to prevent mechanical resonance, combined with high structural strength toward the centre of the turbine blade to provide a strong mounting point. Dampers may be made from the material of the invention, for example, to prevent oscillation of steel wires under tension.

Further possible applications include lightweight transmission shafts for vehicles, MRI (magneto-resonance imaging) magnet gradient housing; MRI magnet gradient vacuum housing; aircraft engine cowl; aircraft engine supporting structure; airframe parts, primary or secondary; control of flutter in flying surfaces; housing for other equipment, e.g., road drills, mining/construction equipment; damping oscillation in automatic systems; changing the load response and geometry response of structures to optimise stress and deflection in design of structures to meet static and or dynamic requirements; improved performance in powder delivery systems; reduction of vehicle noise in motor cars, trains, aeroplanes etc.